FABRICATION OF THICK SILICON DIOXIDE LAYERS USING DRIE, OXIDATION AND TRENCH REFILL

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ABSTRACT

This paper reports a new method of fabricating very thick (10-100μm) silicon dioxide layers without the need for very long deposition or oxidation. DRIE is used to create high aspect ratio trenches and silicon pillars, which are then oxidized and/or refilled with LPCVD oxide to create layers as thick as the DRIE allows. Stiffeners are used to provide support for the pillars during oxidation. Thermal tests show that such thick silicon dioxide diaphragms can effectively thermally isolate heated structures from neighboring structures within a distance of hundreds of microns. The thermal conductivity of the thick SiO_2 is measured to be ~1.1W/(m·K). Such SiO_2 diaphragms of thickness 50-60μm can sustain an extrinsic shear stress up to 3-5MPa.

Keywords: thick silicon dioxide, thermal isolation, high aspect ratio trench, DRIE

INTRODUCTION

SiO_2 is a very desirable MEMS material, because of its low thermal conductivity, low thermal expansion coefficient, and good mechanical strength. Very thick (10-100μm) SiO_2 layers have a variety of applications for thermal isolation in emerging high-temperature systems, for mechanical support of suspend elements in RFMEMS, and for micropackaging. Limited by diffusion/deposition rate, it is not very feasible to produce thick SiO_2 using standard high-temperature oxidation or deposition. One reported approach to fabricating thick SiO_2 involves converting a portion of a silicon substrate to porous silicon by anodization [1], and then oxidizing the porous silicon [2,3] to create a thick SiO_2 of thickness ~25μm. Because pores exist inside the SiO_2, this method may not be suitable for fabricating impermeable SiO_2 layer for applications that need to maintain a pressure difference between the two sides of the layer or contain liquid or gas within the layer.

This paper reports a new method of fabricating silicon dioxide layers of thickness 10-100μm without the need for very long deposition or oxidation. As illustrated in Fig. 1, the technique reported here uses DRIE to create high aspect ratio trenches and silicon pillars, which are then oxidized and/or refilled with LPCVD oxide to create layers as thick as the DRIE allows. Because the trenches are refilled by oxidation and/or LPCVD oxide deposition, the resulting SiO_2 layer is impermeable and can sustain large pressure difference.

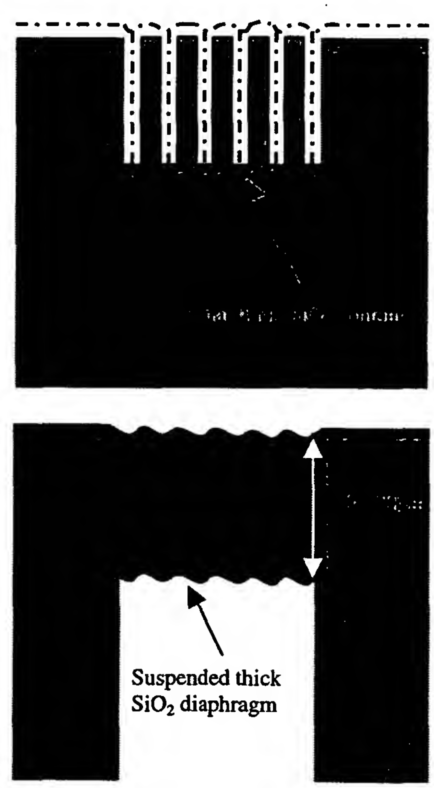
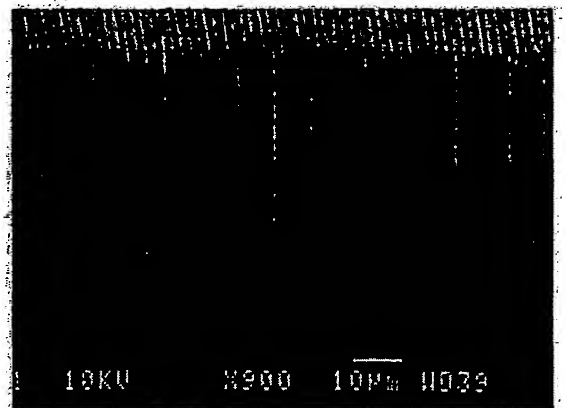


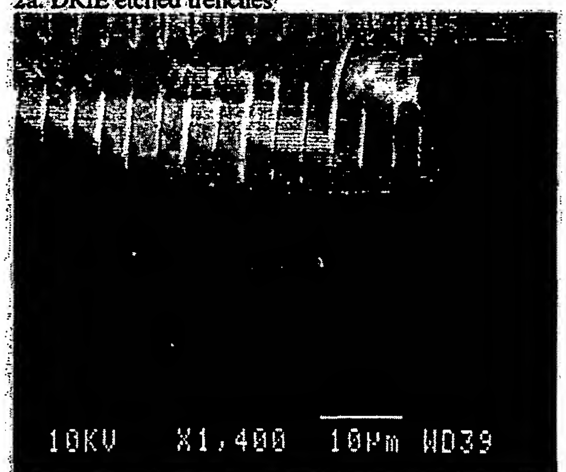
Figure 1: DRIE etched pillars are oxidized and the trenches are refilled by oxidation and/or LPCVD oxide deposition to create a thick oxide layer, which can be released by removing the silicon from backside etching.

FABRICATION

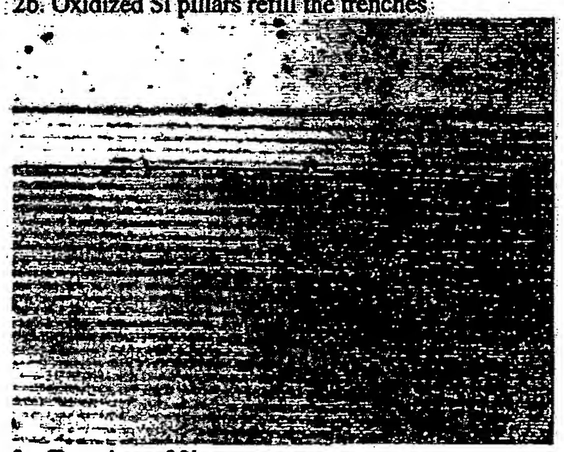
Figure 1 illustrates the process of trench refilling by consuming the Si pillars through oxidation and outgrowth of the oxide into the trench. To obtain an exact refill by oxidation only, the ratio of silicon pillar width to trench opening should be ~0.8. To minimize the time needed for oxidizing the silicon, a narrow layer is preferred. However, a wide silicon pillar is also required to resist damage and stress during processing. As a tradeoff, a mask where the width of Si pillars is ~2.0μm and the trench opening is ~1.5μm was fabricated. These dimensions are chosen to accommodate the undercut of trenches by DRIE. After DRIE etches the high aspect ratio straight trenches in Si (Fig. 2a), the wafer is wet-oxidized for 10 hours at 1100°C to refill the trench (Fig. 2b,c) and join all the SiO_2 layers together to form a thick layer with slight amount of un-oxidized Si enclosed inside the top SiO_2. It can be seen from Fig. 2b that because of the non-ideal sidewall profile formed by bowing effect of DRIE (Fig. 2a), the top and bottom of the thick oxide layer join together, but voids are formed in the middle. For many applications this is acceptable, and for thermal isolation purposes this is even better since the voids reduce thermal conductance, but for some applications requiring excellent mechanical strength it is preferred that the entire layer be of solid material.



2a. DRIE etched trenches



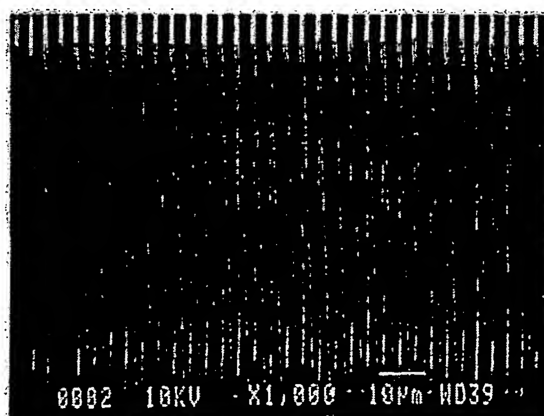
2b. Oxidized Si pillars refill the trenches



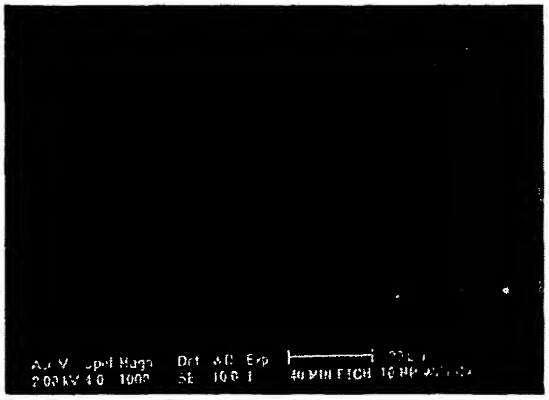
2c. Top view of 2b.

Figure 2: SEM and optical photographs showing trenches refilled only by oxidation of Si pillars.

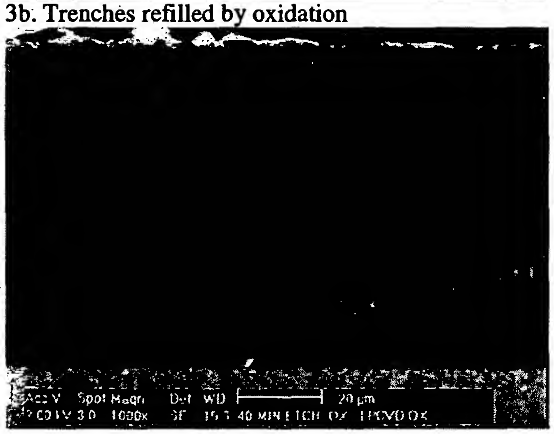
To avoid the formation of voids, we can use both oxidation of Si pillars and further refilling of the trenches using deposited LPCVD oxide. Figure 3 shows the process results of oxidation and LPCVD oxide trench refill. In order to achieve this one needs to change the sidewall profile during trench etching. Using the same mask used to fabricate structures shown in Fig. 2a but adjusting the sidewall profile, a trench with larger width on top and gradually narrower width going towards bottom can be obtained (Fig. 3a). After 10 hours of wet oxidation at 1100°C, the trench bottom gets refilled by lateral growth of oxide, but the top is still open (Fig 3b). 1-2μm of LPCVD oxide is then deposited to refill and seal the opening (Fig. 3c). In these SEM photographs, the oxide regions are shown as the lighter regions because of charging effect (Fig. 3b,c). The thick oxide layer so produced does not have voids in the middle. However, as shown in Fig. 3c,d, the large stress in narrow Si pillars bends the oxide pillars and produces some openings between adjacent areas that cannot be completely filled by LPCVD oxide.



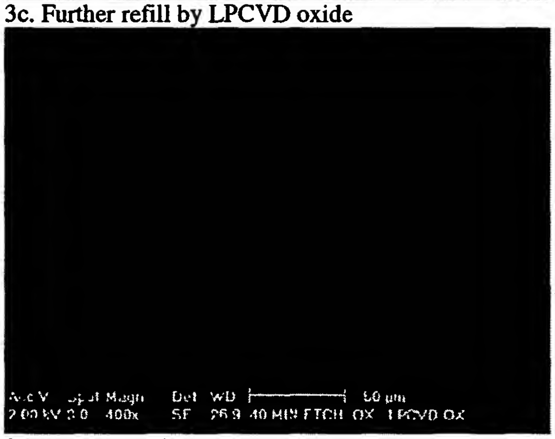
3a. DRIE etched trenches



3b: Trenches refilled by oxidation



3c. Further refill by LPCVD oxide



3d. Top view of 3c.

Figure 3: SEM pictures showing trenches refilled by oxidation plus LPCVD oxide deposition.

This stress problem can be overcome by adding periodic stiffeners perpendicular to the direction of the trenches to provide support for the pillars and by using thicker Si pillar (as shown in Fig 3a, for deep trench lateral etch of DRIE makes Si pillars too thin). A new mask was then designed, where the width of stiffeners is ~1.4um with a pitch of 20μm along the trench direction (at junction regions the pitch is as small as 5μm to further strengthen those particular stressed regions). On the new mask, the width of Si pillars was increased to ~2.8um and the trench opening to ~1.2um. Correspondingly, the wet oxidation time was increased to 15-20 hours at 1100°C to fully oxidize the wider bottom of the resulting Si pillars. Figure 4 shows one preliminary result using stiffeners. It can be seen that the top is totally refilled without bending opening (stiffeners with pitch 50μm have also been tried and it is found that for this pitch, openings larger than 8um are produced in some regions). Although the top surface is not smooth, metal lines of thickness about 1000Å can still be deposited on the top surface by evaporation. Voids have formed at the bottom of this layer because DRIE did not produce the desired sidewall profile. Further characterization of DRIE and modification of stiffeners are needed to improve overall yield and reproducibility.

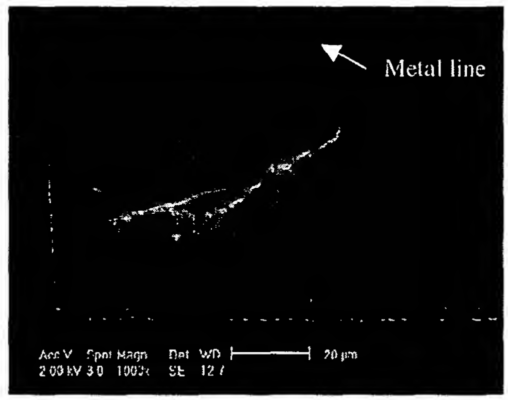


Figure 4: Thick oxide layer using stiffeners. The cross section is perpendicular to trench direction.

TEST RESULTS

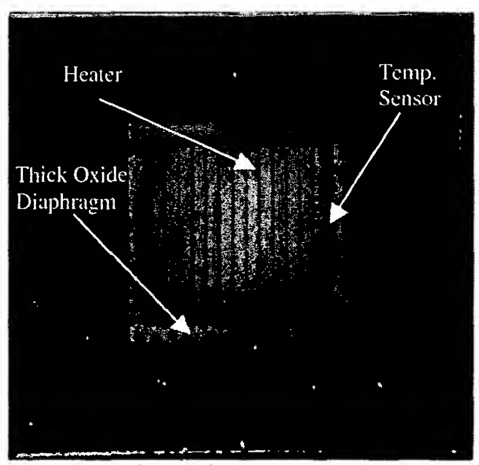


Figure 5: Test structure: a 5mmx5mmx0.5mm Si island suspended on a 300μm wide and 53μm thick oxide ring. Heater and temp. sensors are built to chracterize thermal conductivity of SiO_2.

A structure with a SiO_2 square ring (300μm wide, 53μm thick) surrounding a Si island (5mm×5mm×0.5mm) has been fabricated for thermal and mechanical tests (Fig. 5), where trenches are formed along the ring direction and stiffeners go from Si island to the outside perimeter. Heater and thermistors are fabricated on the island and on the two sides of the ring, respectively, by evaporation of Ti/Pt (200Å/1000Å).

The Si island is heated up by passing current through the heater, and the temperature difference between the two sides of the ring is measured at steady state using the thermistors. Assuming all input power is dissipated through the thick SiO_2 layer (ignore convection and radiation losses under the conditions of small power input and small temperature difference across the SiO_2 layer), the thermal conductivity of the thick SiO_2 is measured to be ~1.1W/(m·K).

Fig. 6 shows the temperature distribution of the heated silicon island and the surrounding area measured by infrared imager. It is seen that the SiO_2 ring can effectively thermally isolate the island from the support ring with a temperature difference of ~190°C when the silicon island is ~440°C at input power of one Watt. It should be pointed out that Fig. 6 is not a direct image from infrared imager but a temperature distribution obtained from infrared data. Since there is large emissivity difference between the Pt heater surface and the rest of top surface, emissivity correction has been made to the Si island based on thermistor measurement. But no correction has been made to the SiO_2 ring and the rest of metal lines. In the measurement, most of the structure is suspended in air and only the two far edges (top and bottom of Fig. 6) are supported by thermal isolation material. Because of the excellent thermal isolation by the thick SiO_2 layer within the small distance of 300μm, the test structure is actually an excellent low-power high-temperature micro-heater.

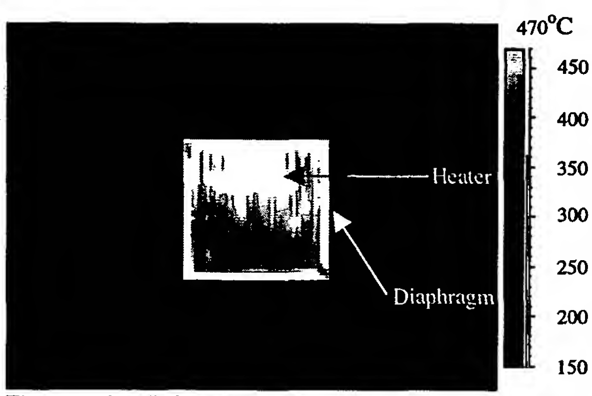


Figure 6: Infrared measurement of temperature distribution across the thick oxide diaphragm. The thick SiO_2 ring surrounds the hot region in the middle.

It should be noted that the thick silicon dioxide layer also provides excellent mechanical support. The test structure with a SiO_2 thickness of 50-60μm has been subjected to an applied differential pressure where the Si island is only supported by the SiO_2 ring. Results show that the ring breaks at a pressure difference about 22-32psi between its two sides. This indicates that the SiO_2 layer has excellent mechanical strength and can sustain an extrinsic shear stress up to 3-5MPa.

CONCLUSION

This paper reports a new method of fabricating very thick (10-100μm) silicon dioxide layers without the need for very long deposition or oxidation. DRIE is used to create high-aspect ratio trenches and silicon pillars, which are then oxidized and/or refilled with LPCVD oxide to create layers as thick as the DRIE allows. Stiffeners are used to provide support for the pillars during oxidation. Thermal tests show that such thick silicon dioxide diaphragms can effectively thermally isolate heated structures from neighboring structures within a distance of hundreds of microns. The thermal conductivity of thick SiO_2 is measured to be ~1.1W/(m·K). The SiO_2 layer has excellent mechanical strength and can sustain large extrinsic shear stress.

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References:

[1] V. Lehmann, "Porous silicon-a new material for MEMS", MEMS '96, pp1-6.

[2] C. Nam, Y.-S. Kwon, "Selective oxidized porous silicon (SOPS) substrate for microwave power chip-packaging", Electrical Performance of Electronic Packaging, IEEE 5th Topical Meeting, 1996 pp202-204.

[3] Ou Haiyan, Yang Qinqing, Lei Hongbing, Wang Hongjie, Wang Qiming, Hu Xiongwei, "Thick SiO_2 layer produced by anodisation", Electronics Letters, V35, 1999 pp1950 -1951.

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